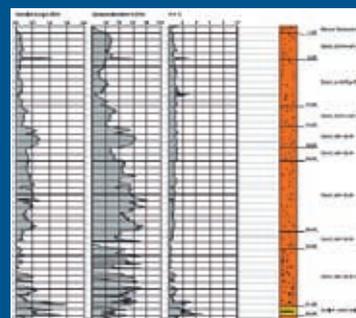


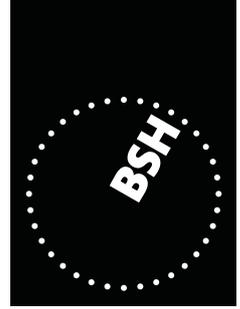


BUNDESAMT FÜR  
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# Standard Ground Investigations

**Minimum requirements for geotechnical surveys and investigations into offshore wind energy structures, offshore stations and power cables**





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Minimum requirements for geotechnical surveys and investigations into offshore wind energy structures, offshore stations and power cables

Second update from 5. 2. 2014

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## Part A – Introduction

### 1 Preliminary remarks

As part of the approval procedure for installing offshore structures such as e.g. wind energy turbines or converters and substations in the exclusive economic zone (EEZ), the applicant or approval holder must demonstrate that the structural integrity is guaranteed in accordance with general technological rules and principles (described in § 5, para. 2 of the Offshore Installations Ordinance – SeeAnIV). The present standard for carrying out geotechnical surveys in preparation for foundation works of offshore structures has been revised under the control of the Federal Maritime and Hydrographic Agency in a second update. It is a technical guideline in connection with the *Minimum Requirements for Construction Design of Offshore Structures in the Exclusive Economic Zone (EEZ)* and is a mandatory component for approval or plan approval decisions in accordance with SeeAnIV. Standardisation aids legal and investment security and is an important factor for the authority responsible for issuing planning permission to fulfil their obligations to treat all applications equally regarding applications to erect offshore structures.

With the available *Standard Ground Investigations* the approval authority publishes the current technical minimum requirements, which includes specific requirements for geological and geotechnical surveys of all structures within and outside offshore wind farms according to the *Standard Design*, e.g. offshore wind energy turbines, offshore converter stations, offshore substations, submarine power cables. Within this second update, this guideline was revised on a scientific basis by a group of engineering and geosciences experts from business, academia and public administration. It takes into account prior experience in erecting offshore structures and the results of current research as well as previous experience with its first and second editions. In addition, the revised standard has a similar format to the *Standard Design*.

This guideline is the result of dedicated and expert-level discussions. The fact that various concepts discussed in the course of the decision making process have not been considered does not imply any criticism of such concepts. The approval authority, after having consulted the experts and having studied the different concepts, in each case selected one of several possible solutions and also allowed alternatives to be considered for given procedures.

## 2 General

Erecting structures to harvest of offshore wind energy in the EEZ is one of those construction measures with a high level of difficulty from a geotechnical standpoint. The ground conditions play a decisive role alongside aspects regarding construction and load. Contrary to widely-held opinion, the sea floor in the EEZ of the North Sea and the Baltic Sea does not comprise of a homogeneous soil with depth and area, but can indeed be extremely heterogeneous on a regional and even local scale. In contrast to constructing with steel or concrete, the material properties of the soil all together cannot be adapted for the structure. For this reason, precise knowledge of the geological conditions and geotechnical characteristics of the subsurface at the actual sites of all components of an offshore wind farm is of great importance to ensure that construction of an offshore wind farm takes place successfully.

The geological makeup of the seabed as a model is the basis for subsequent site investigations, planning and construction. Areas can be demarcated based on the results of a preliminary geological investigation, the expense of geotechnical investigations can be planned and in some circumstances alternative sites can be identified for offshore structures in seas where the seabed consists of localised areas with unsuitable ground conditions.

The design of the foundation structure demands sufficient detailed knowledge of the ground conditions, geotechnical characteristics and the parameters on the site of each structure. For this reason ground investigations must always be carried out with a scope that provides all characteristics of the respective ground conditions can be established in good time before construction of the structure. Geotechnical site investigations and evaluations must therefore be carried out by qualified experts.

The current guideline contains a ground investigation and study programme graduated depending on type and scope for planning and erecting offshore wind energy structures. This programme is coordinated with the requirements for individual phases as part of *Standard Design* and establishes a minimum coverage.

The term *geotechnical survey* covers field site investigations. The generic term *geotechnical survey and investigation* also includes the laboratory tests as well as the expert assessments and evaluations resulting from them.

From a geotechnical viewpoint, the processing steps set out in Table 1 can be distinguished including all necessary professional development and documentation according to chronological order.

**Table 1:** Steps involved in geological and geotechnical surveys and investigations as well as all reporting. Stages 1 to 4 are the development phase, stage 5 is assigned as the construction phase within the context of *Standard Design* (see also Table 2).

Phase	Stage	Geological survey	Geotechnical survey	Report <sup>1</sup>
<b>Development</b>	1	Desk Study		Preliminary geological report, “Geologischer Vorbericht” (content reflects the geological report)
	2	Geophysical investigations		
	3		Preliminary geotechnical investigation	Preliminary geotechnical site survey report, “Baugrundvoruntersuchungsbericht” Soil and foundation expertise report (Development phase), „Baugrund- und Gründungsgutachten (Entwicklungsphase)”
	4	Geophysical postinterpretation including the results of geotechnical survey		Geological report, “Geologischer Bericht” (Findings from 1 to 4)
<b>Construction</b>	5		Main geotechnical investigation	Main geotechnical site survey report, „Baugrundhauptuntersuchungsbericht” Soil and foundation expertise report (Construction phase), “Baugrund- und Gründungsgutachten (Konstruktionsphase)”

The soil and foundation expertise report in the development phase („Baugrund- und Gründungsgutachten (Entwicklungsphase)”) contains mainly an assessment of the foundation which is based on current investigation findings which refer to the method applied and the variants that were designed.

The preliminary geotechnical site survey report (“Baugrundvoruntersuchungsbericht”), soil and foundation expertise (development phase) („Baugrund- und Gründungsgutachten (Entwicklungsphase)”) and geological report (“Geologischer Bericht”) are the rudiments for the design basis and the preliminary design. These must be presented to the Federal Maritime and Hydrographic Agency in accordance with the specifications in the *Standard Design* in a verified format for the first release.

The findings of the geological report are to be integrated into the geotechnical site survey report. Together with the soil and foundation expertise (construction phase) („Baugrund- und Gründungsgutachten (Konstruktionsphase)”) it is part of the rudiments of the basic design. These supporting documents must be presented to the Federal Maritime and Hydrographic Agency in accordance with the specifications in the *Standard Design* in a verified format for the second release.

Part C, Section 2.3.3 contains differing regulations for offshore stations.

<sup>1</sup> See part B, section 7 for the contents of the geological report, see part C section 4 for the contents of the geotechnical site survey report and the soil and foundation expertise.

Further work processes are documented in the following reports and supporting documents:

Construction of foundation work	→	Protocols and assessments
Monitoring of foundation work	→	Report of findings and assessments
Report of findings and assessments	→	Report of findings and assessments

The integration of appropriate work steps in ground investigations and assessments within the phases corresponding to the chronology of events in accordance with the *Standard Design* are illustrated in Table 2.

**Table 2:** Objective and type of geotechnical survey and investigation. The chronology corresponds to the project phases for implementing an offshore wind farm project in accordance with the *Standard Design*.

Phase	Measure	Purpose and objective of exploration	Type of exploration	Work steps/supporting documents
<b>Development</b>	Detailed clarification for the site; Planning including preliminary design of the structure of the plant	<ul style="list-style-type: none"> <li>– Preliminary investigation of the area;</li> <li>– Site selection and preliminary planning of structures;</li> <li>– The preliminary investigation aids decision-making as to whether the planned offshore structures can be built with regard to the ground conditions, and if necessary also which general requirements are essential for the foundation concepts, the foundation structure and the construction process and which measures are important for site investigations.</li> <li>– Fundamentals for invitations to tender on foundation planning and construction</li> </ul>	<ul style="list-style-type: none"> <li>– Review, assessments and evaluations of available supporting documents;</li> <li>– Geological survey in the entire area of the construction site;</li> <li>– Preliminary geotechnical investigations, i.e. representative exploration by means of direct and indirect exposures (a coarse grid over the construction site) and representative determination of the essential parameters and characteristics of the ground conditions.</li> </ul>	<ul style="list-style-type: none"> <li>– Evaluation of available supporting documents;</li> <li>– Geological survey;</li> <li>– Preliminary geotechnical investigations (drilling and/or probing, laboratory and/or field tests);</li> </ul> <p><b>Supporting documents to be submitted with the design basis and the preliminary design:</b></p> <ul style="list-style-type: none"> <li>– Geological report,</li> <li>– Preliminary geotechnical site survey report,</li> <li>– Soil and foundation expertise (Development phase).</li> </ul> <p>All documents audited by an inspector</p>

<b>Construction</b>	Fundamental design (basic design)	<ul style="list-style-type: none"> <li>– The scope of the geotechnical survey and studies, and the choice of investigation methods is determined by the type, size and importance of the construction of the wind energy plants/substations, the uniformity of the structure of the ground conditions, the morphology of the seabed and existing ground types.</li> <li>– The area under investigation must also take possible deviations from the plan into account with regard to the location of structures.</li> <li>– The structure of the ground conditions and the sediment characteristics must be individually recorded for each construction site.</li> </ul>	<ul style="list-style-type: none"> <li>– Review and assessing available supporting documents;</li> <li>– Direct explorations by drilling at the sites of the offshore structures;</li> <li>– Indirect explorations by probing at the sites of the offshore structures;</li> <li>– Laboratory tests via sediment samples on sites</li> </ul>	<ul style="list-style-type: none"> <li>– Main geotechnical investigations (drilling and/or probing, laboratory and/or field tests);</li> </ul> <p><b>Supporting documents to be submitted in connection with the basic design:</b></p> <ul style="list-style-type: none"> <li>– Main geotechnical site survey report,</li> <li>– Soil and foundation expertise, (Construction phase)</li> <li>– Supplementary report regarding cycles,</li> <li>– Geotechnical evidence of structural safety and suitability for use</li> </ul> <p>All documents audited by an inspector</p>
	Implementation planning	<ul style="list-style-type: none"> <li>– Final design of the structure;</li> <li>– The necessary studies depend on the type of foundation. They must be suitable in type and in scope for establishing all dimensions of the foundation and to keep all records appertaining to structural safety and suitability for use</li> </ul>	<ul style="list-style-type: none"> <li>– Supplementary direct exposures at the sites of the foundation elements;</li> <li>– Supplementary indirect explorations at the sites of the foundation elements;</li> <li>– Laboratory tests via sediment samples on sites;</li> <li>– In certain circumstances pile driving and pile load tests may be carried out</li> </ul>	<p>Supplementary exploration and investigation</p> <p><b>Supporting documents to be submitted in connection with the final planning documents:</b></p> <ul style="list-style-type: none"> <li>– Supplementary report regarding cyclical loads in the context of the <i>Standard Design</i> audited by an inspector</li> </ul>

<b>Execution</b>	Erection	<ul style="list-style-type: none"> <li>– Production of the foundation elements;</li> <li>– Inspection of the ground conditions with regard to consistency with the design; inspection of production of the foundation body; monitoring of the development of excess pore water pressure in the load-bearing part of the foundation; monitoring of subsidence and tilting of the foundation body.</li> </ul>	<ul style="list-style-type: none"> <li>– Pile driving log/pile driving report, manufacturing report regarding in-situ concrete piles;</li> <li>– Eventual deformation measurements, as far as is reasonable;</li> <li>– Eventual excess pore water pressure measurements, as far as is reasonable;</li> </ul>	<p>Monitoring in the construction phase</p> <p><b>Supporting documents to be submitted in connection with the inspection documents:</b></p> <ul style="list-style-type: none"> <li>– Reports of findings and assessments in the context of <i>Standard Design</i> audited by an inspector</li> </ul>
<b>Operations</b>	Operations, maintenance and monitoring	<ul style="list-style-type: none"> <li>– Monitoring structural behaviour under working loads;</li> <li>– It should be made possible to be able to take countermeasures in good time against behaviours which differ from those in the design.</li> <li>– Monitoring sediment dynamics in the cable route corridors within and outside the windfarm.</li> </ul>	<ul style="list-style-type: none"> <li>– Deformation measurements on selected offshore structures within the offshore wind farm;</li> <li>– Monitoring scour at regular intervals on each foundation</li> </ul>	<p>Operations monitoring (geotechnical monitoring)</p> <p><b>Supporting documents to be submitted in connection with the inspection documents:</b></p> <ul style="list-style-type: none"> <li>– Reports of findings and assessments audited by an inspector</li> </ul>

### 3 Provisions

This guideline describes the minimum requirements of the Federal Maritime and Hydrographic Agency in its role as an approval authority regarding geotechnical surveys and investigations as well as field and laboratory studies including geotechnical assessments as part of the design basis for the structural components of an offshore wind farm as well as monitoring construction and operations. In this respect the present guideline is based on the *Standard Design* which conforms to Eurocode (EC) and the codes of practice set out in DIN. With regards to subsoil, EC 7 (DIN EN 1997-1 and DIN EN 1997-2) with national annexes and supplementary guidelines (DIN 1054 and DIN 4020 in particular, with their normative references) are decisive. Technical codes of practice, standards, guidelines etc., which are referred to by this standard are valid in their most current version.

Geotechnical surveys and investigations must be coordinated with the planned foundation concept, where on the one hand the difficulties regarding the foundation structure and also the soil conditions and other boundary conditions on the other hand must also be properly taken into account. It must always be carried out in such a scope that all characteristics of the respective ground conditions can be established in good time before construction of the structures.

Methods of carrying out geotechnical surveys and investigations can be divided into the following groups:

- geophysical and
- geotechnical investigation methods.

Geophysical methods are indirect methods (sonars, seismics, echosounding equipment, etc.). Geotechnical methods comprise field and laboratory studies. Field investigations consist of direct exposure, primarily to recover sediment samples (boreholes) and indirect exposure (probes) as well as field tests such as manual vane tests or pressiometric tests in the borehole.

It may be expedient to carry out further investigations to aid planning such as e.g. pile driving or pile load tests. Carrying out pile load tests in the construction phase as part of verification of bearing capacities (execution phase) is regulated in the *Standard Design*.

Sediment characteristics are deducted as part of laboratory or field tests in exceptional circumstances, or derived from field investigations. The type and the scope of such surveys and investigations for individual project phases are illustrated in Table 2.

The concept illustrated in this guideline defines the minimum scope of geotechnical surveys and investigations in general cases. This is specified in Part B and Part C.

#### 4 Geotechnical expert

Guidelines for geotechnical experts (Sachverständige für Geotechnik) in DIN EN 1997 along with the supplementary guidelines in DIN 1054 and DIN 4020 have been refined and adapted for offshore structures as follows:

For planning and carrying out geotechnical surveys, investigations and assessments, the applicant or approval holder must ensure that even in the development phase (in accordance with Part A, Table 2)

- a suitably qualified and independent geotechnical expert
  - with documented experience in such complex construction projects
- has to be involved. This measure should ensure that the soil is recorded as a non-normative part of the supporting structure with regard to size and scope in accordance with accepted technological standards and taken into account in plans and during implementation.

The geotechnical expert acts on behalf of the applicant or approval holder and is responsible for geotechnical surveys, investigations and assessments which are part of the planning basis for the objects of the construction project. The expert's tasks individually arise from DIN 4020.

The geotechnical expert correspondingly develops the geotechnical planning basis for the construction project for the applicant or approval holder. The expert

- plans the preliminary geotechnical survey and the main geotechnical survey,
- accompanies the execution of the preliminary geotechnical survey and the main geotechnical survey,
- develops the geotechnical site survey reports in accordance with Part C, Section 4.2,
- develops the soil and foundation expertise in accordance with Part C, Section 4.3,

- ensures that the findings from the geological and geotechnical ground investigations as part of Table 1, Part A and quality assurance requirements of geological exploration (Part B, Sections 2, 3 and 7.2) are compiled and assessed whilst taking into consideration information from the geoscientists responsible for geological survey,
- states recommendations within the framework of the soil and foundation expertise before preliminary and main site investigations on how the building ground behaviour under cyclical loads should be taken into account for foundation proposals as part of planning.

See Part C, section 4.1 to see the differences in the tasks of the geotechnical expert compared to the tasks of the geotechnical planner (Fachplaner für Geotechnik).

The geotechnical expert must be directly commissioned by the applicant or the approval holder and must also be independent of the company which carries out the geotechnical survey work; the geotechnical expert must carry out tasks autonomously without influence from the applicant or approval holder regardless of their instructions.

Such monitoring of geotechnical surveys by the geotechnical expert or a suitable representative must be proven to the Federal Maritime and Hydrographic Agency.

In addition to tasks appertaining to geotechnical surveys and investigations, the geotechnical expert advises the applicant or approval holder regarding geotechnical planning and construction. This is performed in view of i.e. forming suitable soil models for considering the soil structure interaction between structure and soil, appropriate consideration of certain construction characteristics, of geotechnical monitoring in the construction phase and periodic inspections, especially when using the observational method (Beobachtungsmethode) in accordance with DIN 1054 with regard to the observation programme which is geotechnically necessary, the assessment of such and the requisite preparatory work for measures.

The geotechnical expert

- evaluates those findings regarding the soil which have been fed into the project from other sources with regard to the respective soil model and
- inspects and assesses the appropriate incorporation of specifications in the soil and foundation expertise in the geotechnical planning of the design engineer.

In connection with the assessment of building ground behaviour under typical cyclical load for offshore structures, tight coordination of content is necessary with the designing engineer of the first and second release in accordance with *Standard Design*.

The applicant or approval holder can also consult further independent experts for certain geotechnical questions in cooperation with the geotechnical expert.

## 5 Verification of the supporting documents

The reports and studies listed in Part A section 2 of this guideline are the subject of a project-related verification within the context of Standard Design and are subsequently submitted to the Federal Maritime and Hydrographic Agency at the times shown in Table 2. The soil and foundation expertise (development phase) is a fixed component of the design basis.

## 6 Deviations from the standard

The geotechnical expert can make a reasoned suggestion to the applicant or approval holder to agree to deviations from what is established in this guideline during the ongoing project phase if it can be shown during the course of the project that parts of the survey and investigation programme are inadequate, unnecessary or cannot be carried out in the suggested manner or only by means of disproportionate effort due to site conditions or other reasons. A corresponding proposal can be submitted as part of the regular construction meetings with the Federal Maritime and Hydrographic Agency with consultation from the geotechnical expert and the inspector within the context of *Standard Design*. The approval authority reserves the ability to allow the survey and investigation programme in general to go ahead, to allow it on a case-by-case basis or to adapt it if necessary.

Further statements regarding transitional, deviation and supplementary rules are contained in Part C, section 1.3.

## 7 Updating

The current guideline illustrates the present state of knowledge and technology behind ground surveys and investigations for offshore structures. It is understood as being a dynamic, ongoing concern. New experiences and knowledge which can be expected when implementing further construction projects are observed and added to the work where necessary.

## Part B – Minimum Requirements on geological survey with geophysical methods

### 1 General

Geological survey is one of the requirements for identifying ground types (sediment types), describing their characteristics and for assessing their suitability for construction work. It makes use of modern, high-performance geophysical processes, the results of which must be verified based on direct explorations (drillings). Due to the lack of accessibility to the seabed, geophysical processes are an extremely efficient method to get a general overview of the ground conditions in selected areas within a short period of time and therefore the sediment distribution and tectonic elements are detected in such a manner which enables e.g. the identification of areas with heterogeneous or problematic ground conditions.

Geological exploration is the basis for preliminary and main geotechnical survey and investigation (see Part C, section 2).

Geological investigations can be divided into two steps:

- Geological **reconnaissance** should prove the general suitability of an area and also allow for detailed geological interpretation within an offshore construction site on the basis of a sufficient number of geological sections. In such cases the local conditions for the components of an offshore construction project should be drawn up for all sites as this ensures that unsuitable local ground conditions are identified and if necessary, relocation or optimisation of individual sites is supported.

Different regulations are illustrated for geological survey of offshore stations in Part B, section 6.

- During **inspection** individual sites must be monitored after erection of the structures with regard to potential scouring as well as checking that the minimum cover of submarine power cables is adhered to. In such cases the use of geophysical methods such as e.g. high-performance sonars corresponding to the state of the art should be allowed for in order to adequately detect the local influence of structures on the seabed. The findings must be submitted in a inspection report to the approval authority in the prescribed time periods (see Tables 3 and 4).

### 2 Quality assurance

- The persons in charge must be able to prove that they have sufficient qualifications and proven experience. Their names must be listed in the geological report.
- The data and the assessment thereof must be correct and verifiable.
- Measurement protocols are to be kept; these contain i. e. the external conditions during survey (e.g. wind and ocean conditions, stratification of water bodies, algal bloom), vessel, measurement equipment, measurement configurations and the person in charge for such.
- Position and depth accuracy must conform to the specifications of the International Hydrographic Organisation (2008) for Order 1a and 1b Surveys. Detailed requirements can be seen in Tables 3 and 4.
- The measurement conditions must adhere to the required quality standard in all cases. Based on previous experiences, data quality is no longer guaranteed with a sea state of 5 or higher.

- For geophysical methods a minimum resolution of 1 m is required close to the surface.
- The composition of the seabed in the planning area should be sufficiently captured down to the foundation depth with suitable geophysical methods. In areas with a gas or basin effect where seismic procedures (partially) fail, ground conditions can be sufficiently captured on the basis of geotechnical extraction processes (boreholes and cone penetration testing).
- The findings from geophysical investigations or the interpretation thereof must be checked on the basis of sufficient boreholes and cone penetration testing carried out in the course of the preliminary geotechnical survey. Seismic units are to be connected with the lithological soil profiles.
- An initial assessment should be submitted as a preliminary geological report (Stage 1 – see Part A, Table 1). An interpretation of the geophysical investigations based on the findings of the preliminary geotechnical survey must be prepared and assessed (Stage 3 – see Part A, Table 1) for the geological report (Stage 4 – see part A, Table 1).
- Raw data should be saved in digital format.
- Maps (locations of sections and boreholes, survey tracks, etc.) should be submitted digitally in GIS or CAD format, preferably as shape files.
- The applicant or approval holder is responsible for long-term data archiving including clear documentation of said data.

### 3 Chronological order of events

1. As a basis for planning the site survey a detailed literature review must be drawn up in accordance with DIN 4020, which contains all available and relevant information regarding water depths, geological and hydrographical conditions, existing cables and pipelines in the area, other structures, fishing activities, maritime transport, leisure activities, ordnance, protected and prohibited areas in the area or surrounding areas of where the offshore structures are planned to be located (desk study in accordance with Part A, Table 2).
2. Bathymetric and geophysical investigations (multi beam survey, side scan sonar and seismic recordings as well as magnetometric investigations) must be carried out in the planned area whilst taking the planned sites into consideration.
3. An initial interpretation of the geophysical investigation findings should be submitted as a preliminary geological report (Stage 2 – see Part A, Table 1). The preliminary geological report can be oriented towards the geological report in content terms, see Part B, Section 7.
4. A calibration of the seismic results should also be carried out based on direct and indirect geotechnical methods such as e.g. boreholes and cone penetration testing from the preliminary geotechnical survey, the location of which is expediently coordinated with geological survey. The interpretation of the seismic results must therefore be checked based on the findings of the preliminary geotechnical exploration and be revised in case of considerable deviances if necessary.
5. The geological report must be submitted to the approval authority along with the certified documentation for the first release after all investigations have been concluded.
6. The findings from supplementary geophysical investigations which arise as a result of calibrating seismic investigation findings must be integrated in the main geotechnical site survey report (Stage 5 – see Part A, Table 1).
7. The findings of the geological investigations in the monitoring phase must be submitted as a inspection report.

## 4 Objective

### 4.1 Geological survey

Geological survey is used to record the planning area regarding lithological and tectonic structures as well as general bedding conditions and assessment of the soil from a geological viewpoint. Geophysical profiles must cover the planning area with a regular grid. Changes can be made to this if certain circumstances provide sufficient justification to do so (e.g. following a channel structure in the subsurface). Alongside geological units, obstacles that have been found i.e. wrecks, submarine cables, metal parts and other hazardous objects such as ordnance must also be documented if they are not on the navigational chart.

If differences arise from the findings of the geological survey and the preliminary geotechnical investigation during the development and construction phases which render relocation of the structures necessary, the new sites must be checked regarding their suitability on the basis of additional geophysical records and geotechnical explorations.

### 4.2 Inspection

After construction the area of the seabed around the structures must be monitored for the build-up of scours and the cable route corridors must be monitored to ensure that the minimum cover is ensured or that potential uncovering of the cables does not take place. In addition, the state of safety measures such as e.g. scour protection and gravel dumping should be monitored.

Inspection programmes should be carried out in accordance with the requirements of periodic inspections according to *Standard Design*.

In the first couple of years after construction of offshore structures, inspection should take place once per year as a normal case, namely early in the year (directly after stormy periods). The findings should be presented in a inspection report as part of periodic investigations, and this should be submitted to the approval authority at the end of the calendar year.

## 5 Technical guidelines

In Tables 3 to 6 the objectives, scope, time frames, methods and presentation of results with all required technical details is shown for the respective procedure, and these give an overview regarding the minimum requirements of geophysical investigations for geological exploration and inspection.

**Table 3:** Requirements of echo-sounding measurements.

	<b>Geological survey</b>	<b>Inspection</b>
<b>Objectives</b>	<ul style="list-style-type: none"> <li>• Detection of local depth changes (potential scour)</li> </ul>	
<b>Scope</b>	<ul style="list-style-type: none"> <li>• Full coverage</li> </ul>	<ul style="list-style-type: none"> <li>• In the local surroundings of the foundation elements of the offshore structures</li> </ul>
<b>Timing</b>	<ul style="list-style-type: none"> <li>• Once</li> </ul>	<ul style="list-style-type: none"> <li>• In the initial years after completion check once per year, early on in the year</li> </ul>
<b>Method</b>	<ul style="list-style-type: none"> <li>• Multi-beam echo sounder (MBES)</li> <li>• Positioning better than 5 m + 5 % of water depth as well as</li> <li>• accuracy for reduced depths in accordance with IHO (2008) for Order 1b surveys</li> </ul>	<ul style="list-style-type: none"> <li>• Multi-beam echo sounder (MBES)</li> <li>• Positioning better than 5 m + 5 % of water depth as well as</li> <li>• accuracy for reduced depths in accordance with IHO (2008) for Order 1a surveys</li> </ul>
<b>Presentation of results</b>	<ul style="list-style-type: none"> <li>• Bathymetric map of the areas surveyed</li> <li>• Water depths must be adjusted for water sound propagation and illustrated based on CD (LAT) (Tidal correction)</li> <li>• Data must also be submitted in digital format and with sufficient supporting documentation</li> </ul>	<ul style="list-style-type: none"> <li>• Bathymetric map of the areas measured</li> <li>• Water depths must be adjusted for water sound propagation and illustrated based on CD (LAT) (Tidal correction)</li> <li>• Data must also be submitted in digital format and with sufficient supporting documentation</li> </ul>

**Table 4:** Requirements of side scan sonar (SSS) investigations.

	<b>Geological survey</b>	<b>Inspection</b>
<b>Objectives</b>	<ul style="list-style-type: none"> <li>• Summary of the present sediment types and structures.</li> <li>• Validation and calibration of the findings by means of ground truthing.</li> </ul>	<ul style="list-style-type: none"> <li>• Detecting erosion areas, scour or obstacles.</li> <li>• Validation and calibration of the findings by means of ground truthing.</li> </ul>
<b>Scope</b>	<ul style="list-style-type: none"> <li>• Sections in accordance with seismic measurements or extensively over the offshore construction site</li> <li>• Extensively within areas with heterogeneous sediment cover</li> </ul>	<ul style="list-style-type: none"> <li>• In the local surroundings of the foundation elements of the offshore structures</li> </ul>
<b>Timing</b>	<ul style="list-style-type: none"> <li>• Once</li> </ul>	<ul style="list-style-type: none"> <li>• In the initial years after completion check once per year, early on in the year</li> </ul>
<b>Method</b>	<ul style="list-style-type: none"> <li>• Frequency of 100 kHz or higher</li> <li>• Measured area is a maximum of 2 x 100 m</li> <li>• Recognition of objects &gt; 1 m in grid spacing<sup>2</sup></li> <li>• Digital recording</li> <li>• Cruising speed max. 4 kn, provided that the equipment used does not demonstrably allow for higher cruising speeds</li> <li>• Positioning of the equipment is better than 10 m</li> </ul>	<ul style="list-style-type: none"> <li>• Frequency of 100 kHz or higher</li> <li>• Measured area is a maximum of 2 x 75 m</li> <li>• Recognition of objects &gt; 1 m in grid spacing</li> <li>• Digital recording</li> <li>• Cruising speed max. 4 kn</li> <li>• Positioning of the equipment is better than 10 m</li> </ul>
<b>Presentation of results</b>	<ul style="list-style-type: none"> <li>• Digital SSS mosaic of the sections (horizontal resolution from 0.5 m)</li> <li>• Map with interpretations of the side scan sonar sections</li> <li>• Data must also be submitted in digital format and with sufficient supporting documentation (internal format)</li> </ul>	<ul style="list-style-type: none"> <li>• Digital SSS mosaic of the sections (horizontal resolution from 0.5 m)</li> <li>• Map with interpretations of the side scan sonar sections</li> <li>• Data must also be submitted in digital format and with sufficient supporting documentation (internal format)</li> </ul>

<sup>2</sup> modelled on IHO (2008) for Special Order Surveys.

**Table 5:** Requirements of seismic investigations.

	<b>Geological survey</b>
<b>Objectives</b>	<ul style="list-style-type: none"> <li>• Detecting the type and location of geological units</li> </ul>
<b>Scope</b>	<ul style="list-style-type: none"> <li>• Use of grids for exploration of the offshore construction site <i>Recommendation:</i> Spacing of the seismic grid of 500 m in longitudinal and transverse directions. In case of differences in similar grid positions due to certain features of the construction site, a maximum spacing of 1000 m must not be exceeded.</li> </ul>
<b>Timing</b>	<ul style="list-style-type: none"> <li>• Once</li> </ul>
<b>Method</b>	<ul style="list-style-type: none"> <li>• Boomers or alternative systems with comparable or better performance and sufficient signal penetration, resolution of at least 1 m required close to the surface</li> <li>• Supplementary sub-bottom profilers or chirp sonar for areas close to the surface (e.g. along the planned cable route corridors), vertical resolution of at least 0.5 m</li> <li>• Cruising speed: max. 4 kn</li> <li>• Usage up to sea state of 4, when systems are used together with a so-called “motion sensor” then usage up to swell 5 or 6 is justifiable</li> </ul>
<b>Presentation of results</b>	<ul style="list-style-type: none"> <li>• Section with interpretation (i. e. geological longitudinal sections and transects)</li> <li>• Map with the geographical location of geological units and structure elements (e.g. isolines map)</li> <li>• Data must also be submitted in digital format and with sufficient supporting documentation (internal format).</li> </ul>

Before carrying out geotechnical surveys (boreholes, probes), an investigation should be carried out for reasons of safety in accordance with DIN 4020 to determine whether ordnance or cables are present with a magnetometer or an active metal detection system.

**Table 6:** Requirements of magnetometers or active metal detection systems (recommended).

	<b>Geological survey</b>
<b>Objectives</b>	<ul style="list-style-type: none"> <li>• Primary inspection of the study area for wrecks, cables in and out of operation, metal parts and other hazardous objects such as e.g. ordnance (provided it can be detected)</li> </ul>
<b>Scope</b>	<ul style="list-style-type: none"> <li>• Depending on necessity in accordance with the findings of the Desk Study (Stage 1, see Table 1)</li> <li>• In any case within ammunition prone areas and areas close by, sections corresponding to the seismic profile grid or covering the whole area if necessary</li> </ul>
<b>Timing</b>	<ul style="list-style-type: none"> <li>• If required</li> </ul>
<b>Method</b>	<ul style="list-style-type: none"> <li>• Magnetometer</li> <li>• If ordnance is suspected, or within areas where munitions are suspected, then within a gradiometer arrangement</li> <li>• Resolution &lt; 0.1 nT</li> <li>• Alternatively: an active metal detection system which measures total intensity</li> <li>• Cruising speed: max. 4 kn</li> <li>• Use up to a maximum sea state of 4</li> <li>• The altitude of the magnetometer over the ground should be chosen depending on the geophysical study findings. If ordnance is suspected, then lower than 4 m.</li> </ul>
<b>Presentation of results</b>	<ul style="list-style-type: none"> <li>• Map with investigation findings</li> <li>• List of anomalies discovered incl. comparison with the findings of SSS investigations. The data must also be submitted in digital format and with sufficient supporting documentation.</li> </ul>

## 6 Offshore stations

Offshore converter stations are individual structures which require individual geological survey. Survey must be provided in a comprehensive manner adapted to the size of the construction site in accordance with Part B, Sections 4 and 5.

Geological survey is not necessary for offshore substations or other stations within the planned wind farm.

## 7 Geological report

### 7.1 Purpose

The findings of geophysical recordings and the preliminary geotechnical investigation are compiled together and assessed in the geological report. The report provides a basis for further planning and contains a description of the geological model upon which the structures should be erected. It should be set up from an engineering geological point of view and should, together with geotechnical documents (see Part A, Section 2), serve as empirical evidence for validation of the planned sites and for selection of suitable foundation types.

## 7.2 Content

The geological report contains at least the following specifications:

- short project description,
- objective of the investigations,
- the company and persons involved,
- description of the investigations carried out
  - period of time for work carried out in the sea and in the laboratory,
  - description of all measuring systems and equipment used including specifications regarding ranges of measurement and tolerance of individual parameters,
  - relevant specifications from measuring protocols such as e.g. ambient conditions, sound profiles in water, etc.,
  - data processing,
- findings of the Desk Study,
- summary of the findings of individual investigations (e.g. bathymetry, echo-sounding measurements, seismic surveys, boreholes, probes). Summary of all relevant data (e.g. back-scattering mosaic from side scan sonar investigations, seismograms) can be found in the preliminary geological report,
- comparison of acoustic description of the sediment units with lithological description from the stratification record (e.g. in a table) and cone penetration testing findings, geological interpretation
- lists of anomalies discovered, and recommendations for further handling if necessary,
- locations of sections and boreholes, drilling logs in accordance with DIN 4023 including the range of tolerance of each measurement system used, the positional accuracy of the sections and exposures and the reference system used.
- presentation of findings in the form of geological longitudinal and cross sections of suitable scale,
- assessment of the findings, illustration of the interpretation limits and remaining exploration risks, and recommendations for further investigations if required,
- summary,
- digital data medium with digital map in CAD or GIS format, preferably as shape files and
- delivery of the processed seismic survey together with a freely available reader on digital data media.

Unpublished results from neighbouring areas can only be accessed if these are published in the report with the associated documentation.

## 7.3 Specifications

Reference system: ETRS89 (WGS 84)  
Projection: Corresponding UTM zone  
Depth information: based on CD (LAT) specifying the reference level

## Part C: Minimum Requirements on geotechnical investigations as a basis for planning and designing offshore structures

### 1 Regulations and codes of practice

#### 1.1 General

The construction of offshore wind energy converters involves a high degree of difficulty, their foundations are classified under geotechnical category 3 (*earth and foundation structures and geotechnical measures involving a high geotechnical risk; difficult design and/or difficult soil conditions, and unusual loading cases*). These require geotechnical surveys, investigations and assessments by a geotechnical expert with in-depth knowledge and wide-ranging experience in this field (see Part A, section 4).

Minimum requirements of geotechnical field and laboratory investigations as part of fundamental design are specified in Part C, sections 2 and 3. In addition, necessary investigations arise due to specific requirements of the respective foundation structures and soil situation, particularly with innovative solutions.

#### 1.2 Standards

The geotechnical expert must apply the following standards with corrections and normative references:

DIN EN 1997-2: Eurocode 7: Geotechnical design – Part 2: Ground investigation and testing  
DIN EN 1997-2/NA: National Annex – Nationally determined parameters – Eurocode 7: Geotechnical design – Part 2: Ground investigation and testing  
DIN 4020: Geotechnical investigations for civil engineering purposes – supplementary guidelines to DIN EN 1997-2

It must be considered that these standards are used in conjunction with the following codes:

DIN EN 1997-1: Eurocode 7: Geotechnical design – Part 1: General rules  
DIN EN 1997-1/NA: National Annex – Nationally determined parameters – Eurocode 7: Geotechnical design – Part 1: General rules  
DIN 1054: Soil – verification of safety in earthwork and foundation work – supplementary guidelines to DIN EN 1997-1

In addition, relevant DIN norms also apply for planning, execution, documentation and assessment of field and laboratory investigations and these are supplemented by the stipulations of this guideline.

The most recent version of standards published as a white paper applies in all cases.

The Federal Maritime and Hydrographic Agency reserves the right to remove individual standards from having to be applied.

### **1.3 Transitional, deviation and supplementary rules**

Transitional arrangements must be agreed with the Federal Maritime and Hydrographic Agency on a case-by-case basis.

Differences from the codes of practice named in Part C, section 1.2 are permitted when taking the unusual conditions for offshore structures into account. Differences should be made known and reasons for such should be stated by the geotechnical engineer. Final approval from the Federal Maritime and Hydrographic Agency to such changes is necessary, so that they can consult appropriate inspectors.

Supplements to the stated standards by means of further codes of practice, guidelines and recommendations are to be carried out, if and provided that the latter do not contain any guidelines or are not applicable for a topic on a case-by-case basis, and if certain aspects of geotechnical surveys and investigations for offshore wind farms are not or insufficiently taken into account.

## **2 Requirements on offshore investigations**

### **2.1 Planning of field investigations**

The geotechnical expert, in co-operation with the design engineer, selects suitable survey and investigation methods on the basis of the preliminary geological report and determines the number and arrangement of exploration sites and the site survey depth in each case.

In the course of the geotechnical site investigations, the geotechnical expert has to decide whether additional investigations or different methods are required, which are then applied according to his/her instructions. This is particularly likely in case of inhomogeneous or otherwise unfavourable soil conditions.

The geotechnical expert may commission adequately qualified personnel to assist him/her in monitoring the field investigations.

### **2.2 Investigation methods**

Direct and indirect investigation methods will be distinguished in the following.

Important technical normative information for direct and indirect investigation methods as part of geotechnical surveys can be found in DIN EN ISO 22475-1 and the standards set out in DIN EN ISO 22476. Drilling, sampling methods and probes should satisfy the stated standards regardless of the working platform or carrier technology over the entire section under investigation.

Geodetic measurement of all investigation sites must be in accordance with the demands of IHO (2008) for Order 1 surveys and must be documented accordingly. DIN EN ISO 10012 defines a common binding framework for correct execution.

#### **2.2.1 Direct explorations (Drilling)**

DIN EN ISO 22475-1 lists suitable onshore drilling methods, which can also be used offshore if jack-up rigs are used as a working platform. When using corresponding heave motion compensation systems, these processes are generally available also for the use of floating working platforms.

Typical drilling procedures when using drillships can be used e.g. McClelland & Reifel (1986). Further information is also available in DIN EN ISO 19901-8.

### 2.2.2 Indirect explorations (Sounding and in-situ measurements)

Cone penetration tests (CPT) in accordance with DIN EN ISO 22476-1 measure the cone tip resistance and local sleeve friction as a minimum requirement. In addition, pore water pressure can be measured (CPTu) as well as other parameters (e.g. vane shear, boom tilt, and probe speed).

CPT testing is either carried out in a continuous manner from the seabed (seabed CPT) or from a fixed working platform (topdrive CPT) or as a discontinuous probe from the borehole bottom (downhole CPT). Further guidelines and notes for carrying out and assessing cone penetration testing are contained in Lunne et al. (1997) inter alia.

In the borehole dynamic penetration test (BDP) in accordance with DIN 4094-2 the sounding device is driven into the bottom of a borehole while counting the number of blows required [ $n_{30}$ ].

A summary of other indirect investigation methods (vane shear, pressure meter, temperature probes, borehole geophysics, etc.) is provided by e.g. DIN EN ISO 19901-8 or Balthes et al. (2005).

### 2.2.3 Soil and rock sampling

The geotechnical expert determines the frequency of sampling depending on the foundation soil strata according to DIN 4020. Certain offshore conditions should be taken into account according to e.g., Fugro-McClelland Ltd. (1993), McClelland & Reifel [1986], API RP 2A-WSD, DNV-OS-J101, DNV Classification Notes No. 30.4 or DIN EN ISO 19901-8.

The drilling methods and the extraction unit for loose rock (soils) must correspond to sampling category A in accordance with DIN EN ISO 22475-1 and should be selected such that in case of cohesive soils samples of at least grade 2 and as many grade 1 samples can be obtained as possible. The sediment samples must be undisturbed at least in their composition, water content, density, and permeability.

If grade 1 or 2 samples cannot be achieved using available drilling methods in cohesive soils, there is a possibility of taking sediment samples from the borehole bottom with a suitable extraction unit corresponding to sampling category A in accordance with DIN EN ISO 22475-1.

It has been found that thin wall tube samplers (wall thickness 2 mm) are the most suitable tool for taking soil samples both from normally consolidated cohesive soils. Conventional Shelby tubes or thin-wall samplers are preferably used for this purpose. Samples are preferably taken as push samples.

Overconsolidated cohesive soils can be sampled using special thick-walled samplers (wall thickness 4.5 mm); either push or hammer samples can be taken with this method.

In case of non-cohesive soils, sediment samples of at least grade 4 must be obtained, which remain unchanged with regard to their composition. Obtaining sediment samples which are at least grade 3 is targeted for non-cohesive soils. In case of core-compatible non-cohesive soils, driving and/or rotating drilling processes with or without a rinsing aid which steadily gains core soil samples in accordance with DIN EN ISO 22475-1 can be used.

The drilling procedure for solid rock (rock and solidified loose rocks) should be selected such that with a category A sampling process in accordance with DIN EN ISO 22475-1 sediment cores can be obtained that are at least grade 2. The core barrel drilling process with double or triple tube is especially suitable for sampling in solid rock.

Sampling and the required quantities to be sampled should be planned and carried out regarding the planned laboratory tests with the necessary testing technology on the one hand and regarding the composition and the degree of homogeneity of the soil on the other hand.

A sample diameter of  $D = 100$  mm is recommended for soil mechanical laboratory tests on homogeneous cohesive sediment samples and for rock mechanical laboratory tests on solid rock samples.

Standard values for sample diameters and sample lengths for loose and solid rock

- for a drilling process which steadily obtains core soil and rock samples are:  $D = 100$  mm,  $L = 1000$  mm
- when taking soil samples with a thin or thick-walled sampling device from the bottom of a borehole in accordance with DIN EN 22475-1:  $D = 114$  mm,  $L = \text{approx. } 250$  mm
- when taking pressure and pile core samples from the bottom of a borehole whilst using specific sampling technology meant for offshore use:  $D = 67$  mm, and with particularly densely packed soils also  $D = 46$  mm.

Further requirements can be found in DIN EN ISO 22475-1.

The geotechnical expert shall decide, taking the requirements of DIN EN ISO 22475-1 into consideration, on whether the soil or rock samples are treated, transported and stored for laboratory analysis or whether preliminary material testing is to be carried out on board the ship or the jack-up rig.

Representative sediment samples for subsequent inspections or additional laboratory tests must be stored for at least 5 years after sampling takes place. Storage must be protected from the weather and remain cool and frost-free. Spot samples in sample containers and core probes in core boxes and liners must be stored in such a manner that mechanical soil and rock properties of the samples remain unchanged.

## **2.3 Investigation steps**

### **2.3.1 Preliminary geotechnical investigation**

In the course of preliminary investigations of the wind farm area (Step 3, see Table 1, Section A), at least 10% of all planned turbine sites are subjected to a geotechnical survey and investigation whilst taking the following aspects into consideration. Different regulations are illustrated for preliminary geotechnical investigation of offshore stations in Part C, section 2.3.3.

The location of soil investigation is determined by the geotechnical expert and is based on the findings of geological survey whilst taking geological structures into consideration and also being representative of the area of the construction site.

The type of investigation method (drilling, cone penetration testing or if necessary a combination of drilling and cone penetration testing) is to be decided upon by the geotechnical expert whilst taking the expected soil conditions especially those based on the findings of geological survey as well as the planned foundation type.

In predominantly sandy subsoil layers such as e.g. in many project areas in the German North Sea, cone penetration testing should be carried out to find out the bulk density in all sites where the preliminary investigation takes place. It must also be ensured that representative sediment samples are obtained from a sufficient number of boreholes.

In many project areas within the German Baltic Sea which have a predominantly cohesive subsoil layers as well as soils similar to solid rock (e.g. chalk), boreholes are necessary to obtain representative sediment samples at all sites within the course of preliminary exploration. The need for cone penetration testing is determined by the geotechnical expert on a case-by-case basis.

The exploration depth of borings and cone penetration tests shall be sufficient to allow possible foundation types to be assessed within the framework of preliminary design planning. Therefore, the investigation depth has to be determined by the geotechnical expert, in co-ordination with the design engineer.

It is recommended that the survey concept is agreed upon with the certifying body within the meaning of the *Standard Design*.

### **2.3.2 Main geotechnical investigation**

In the course of main geotechnical investigations (step 5, Part A, Table 1), at least one site investigation has to be carried out at each turbine site. This may be sufficient with homogeneous soil conditions. However, when soil conditions are inhomogeneous or otherwise unfavourable, or in case of tripod, jacket or gravity foundations, a larger number of site investigations is normally required for execution planning. The geotechnical expert shall decide in this case. The investigation method to be used (drilling, cone penetration or a combination of both) shall be determined by the geotechnical expert taking into account the expected soil strata, the results of preliminary investigation, and the foundation type.

Different regulations are illustrated for main geotechnical investigation of offshore stations in Part C, section 2.3.3.

The investigation depth, as a minimum, shall meet the requirements of design planning and thus has to be determined by the geotechnical expert, in co-ordination with the design engineer (see chapter 2.3.1).

### **2.3.3 Special regulations for offshore stations**

Usually a minimum of four ground investigations for foundation structures are carried out in the corner areas of the structure or in all sites of the foundation elements (piles). The respective distance between individual investigations and the assigned foundation element (pile) must be no more than 30 m for large foundation structures, otherwise additional explorations must be arranged.

For offshore stations (as well as for external converter stations as well as substations or other stations within the wind farm) the steps for preliminary and main investigation (development and construction phase – see Part A, Section 2) can be formally summarised. The associated reports should be submitted to the Federal Maritime and Hydrographic Agency in a certified manner for the second release at the latest. If necessary, submission of the first release is also possible.

Also, the guidelines apply in accordance with Sections 2.3.1 and 2.3.2.

### **2.3.4 Supplementary investigations**

Supplementary investigations or field tests such as e.g. pile driving or pile load tests may become necessary as a result of the design work, the geotechnical verification of the initial design or the invitation to tender, especially with separate proposals. The same principles as for site investigations apply here.

The findings of the geotechnical investigation should be compared with the findings of the geophysical survey, and the geophysical measurements should be subsequently interpreted on the basis of the geotechnical investigation.

### 3 Requirements on laboratory testing

#### 3.1 Standard laboratory tests

The standard laboratory tests for cohesive and non-cohesive soils are set out in Tables 7 and 8 which are suitable for describing the state of the soil as well as for determining the fundamental characteristics of the ground conditions. The geotechnical expert determines the tests to be carried out on a case-by-case basis, the type of testing methods, the sample quality required as well as the soil mechanical parameters. Further laboratory tests may be expedient for measuring the foundation structure depending on the planned foundation type.

**Table 7:** Suitable laboratory tests for assessing non-cohesive soils.

Test type	Standard	Quality of the sample (DIN EN ISO 22475-1)	Soil mechanical parameter
<b>Classification and status description</b>			
Particle size distribution	DIN 18123	Min. 4	degree of non-uniformity, coefficient of gradation
Bulk density	DIN 18126	Min. 4	Loosest and densest state
Density	DIN 18125-1	Min. 2	density, buoyant density
Lime content	DIN 18129	Min. 4 (5)	Lime content
<b>Deformation behaviour</b>			
Compression test (Oedometer test)	DIN 18135	4 but mounted sample with initial in-situ density	Stiffness modulus, coefficient of consolidation, coefficient of secondary compression, derived: coefficient of water permeability
Triaxial test	DIN 18137-2	1, but also treated samples	Shear stress-strain curves, volume change and axial deformation
<b>Shear strength</b>			
Direct shear test	DIN 18137-3	1, but also treated samples	Friction angle $\varphi'$ ( $c' = 0$ )
Triaxial test	DIN 18137-2	1, but also treated samples	Friction angle $\varphi'$ ( $c' = 0$ )

It can be expedient to carry out investigations of a limited scope on board the survey vessel or the jack-up rig to obtain findings for planning further field investigations which can subsequently be carried out relatively promptly.

**Table 8:** Suitable laboratory tests for assessing cohesive soils.

Test type	Standard	Quality class of sample (DIN EN ISO 22475-1)	Soil mechanical parameter
<b>Classification and status description</b>			
Particle size distribution	DIN 18123	Min. 4	degree of non-uniformity, coefficient of gradation
Water content	DIN 18121-1 DIN 18121-2	Min. 3	Water content of soil
Water permeability	DIN 18130-1	minimum of grade 2 if sample has been adjusted to the required density using Proctor compacting equipment	coefficient of water permeability
Density	DIN 18125-1	Min. 2	density, buoyant density
Consistency limits	DIN 18122-1 DIN 18122-2	Min. 4	Liquid limit, plastic limit, shrinkage limit, plasticity index, consistency index
<b>Deformation behaviour</b>			
Compression test (oedometer test)	DIN 18135	1 <sup>3</sup>	Stiffness modulus, Pre-stressing of soil, coefficients of consolidation, secondary compression, water permeability
Triaxial test	DIN 18137-2	1 <sup>3</sup>	Shear stress-strain curves; volume change and axial deformation
<b>Shear strength</b>			
Laboratory vane test	Laboratory tests not currently standardised	1 <sup>3</sup>	Undrained shear strength $c_u$
Direct shear test	DIN 18137-3	1 <sup>3</sup>	effective friction angle $\varphi'$ , effective cohesion $c'$
Triaxial test	DIN 18137-2	1 <sup>3</sup>	Shear parameters depending on type of test: UU test: $c_u, \varphi_u$ CU test: $c^u, \varphi^u$ CCV test: $c', \varphi'$

### 3.2 Tests to analyze soil behaviour under cyclical loading

Pressure changes in the soil can be either directly or indirectly induced by load transfer through the structure caused by waves, currents and wind; these can exert a crucial influence on the load-bearing behaviour of the soil and therefore also the foundation. Cyclical load actions must therefore be taken into account in an appropriate manner when measuring the foundations (see e.g. DIN 1054).

<sup>3</sup> With regard to the grades which can be achieved, see Part C, Section 2.2.3.

Execution of cyclical tests and assessment therefore is not currently standardised. The laboratories commissioned to carry out these investigations must have documented experience with cyclical tests.

The type, number and boundary conditions of cyclical tests must be determined depending on the planned foundation. The number of cyclical loads and the size of the cyclical load level in the test must be chosen such that the test findings for the stated problem site are clear and provide comprehensive information.

In this context, i.e. the liquefaction potential of in-situ soils may have to be analysed using suitable methods and taking into account the type of structure and load conditions if this is considered necessary by the geotechnical expert in co-ordination with the design engineer. A reliable and standardised concept for determining the liquefaction potential is not yet available.

Information regarding cyclical tests is contained in e.g. *Recommendations of the Soil Dynamics working group* of the DGGT – German Geotechnical Society (2002). Suitable test types along with their boundary conditions are listed to examine the influence of cyclical pressure changes on pile foundations in the EAP (2012), Chapter 13. Such recommendations do not yet exist for other foundation types such as heavy weight foundations or suction caissons.

## 4 Geotechnical documents

### 4.1 Preliminary remarks

The findings of the geotechnical survey and investigation including assessments and recommendations from the geotechnical expert are to be submitted in report format in the respective project phases or releases. In this case the geotechnical site survey report, which corresponds to the geotechnical survey report in accordance with DIN EN 1997-2 and DIN 4020 covers contents which are listed in Part C, Section 4.2. The soil and foundation expertise assesses the findings of the geotechnical site survey report, gives recommendations for foundations as well as implications for the structure and execution whilst containing characteristic values for ground conditions (see Part C, Section 4.3).

The geotechnical site survey report and the soil and foundation expertise must be co-ordinated and together form the geotechnical report in accordance with DIN 4020 (see DIN EN 1997-2, A7). A formal compilation of the geotechnical site survey report and the soil and foundation expertise is waived for the Federal Maritime and Hydrographic Agency.

Both reports together form the basis for geotechnical planning and are also a component of the design basis which is to be drawn up or updated for the respective project phases.

The geotechnical design development is the responsibility of a geotechnical planner (Fachplaner für Geotechnik) on behalf of the design engineer, who develops the geotechnical design of the foundation elements together with certificates of their structural safety and suitability for use in a geotechnical design report in accordance with DIN EN 1997-1 (geotechnical planning contribution). The geotechnical design report includes the geotechnical site survey report and the soil and foundation expertise by reference.

In accordance with DIN EN 1997-1, 2.8 A note to (3), the geotechnical design report and geotechnical report can be carried out by one person provided that they have the necessary knowledge and experience. The applicant or approval holder must ensure that the respective areas of responsibility are kept separate.

Table 9 summarises the main content as well as report designations in this guideline and their equivalents in the essential standards.

**Table 9:** Areas of responsibility, contents and designations of reports in accordance with Federal Maritime and Hydrographic Agency guidelines and comparisons with the corresponding definitions in essential standards

Core contents	Responsibility	Descriptions in accordance with		
		Federal Maritime and Hydrographic Agency guidelines (from 2014)	DIN	EC-7
Geotechnical site study report	SVGt	Preliminary geotechnical site survey report Main geotechnical site survey report	Geotechnical Report (DIN 4020)	Geotechnical design report (DIN EN 1997-1)
Characteristic values, soil model and foundation proposal	SVGt	Soil and foundation expertise (Development phase) Soil and foundation expertise (Construction phase)		
Structural safety and suitability for use	FPGt (EV)	Geotechnical design report (with supplementary cyclical report)	Geotechnical design report (DIN 1054:2005)	

SVGt Geotechnical engineer (Sachverständiger für Geotechnik) 2014

FPGt (EV) Geotechnical planner on behalf of the design engineer (Fachplaner für Geotechnik)

## 4.2 Geotechnical site survey reports

### 4.2.1 Content of the geotechnical site survey reports

The geotechnical site survey reports, i. e. the preliminary or main geotechnical site survey report, must contain at least the following as an independent part of the *geotechnical report* in accordance with DIN 4020 in the respective project phase except a precise specification of the objective of the investigation as well as documentation of the supporting documents made available regarding the structure:

- general specifications regarding the construction task,
- specifications regarding geological conditions,
- specifications and boundary conditions regarding field and laboratory tests,
- findings from boreholes and probes,
- specifications for determining site-based water depth, tide and correction of water depth depending on time, including specification of the reference level (e. g. chart datum (LAT), MSL),
- specifications regarding geodetic measurements of geotechnical surveys including reference (e. g. World Geodetic System 1984, UTM),
- specifications for calculating, correlating and interpreting (classification) of the in-situ test results,
- bottom profile with soil types and the altitude of boundaries between strata relative to the seabed and sea level incl. specification of the reference system (e. g. chart datum (LAT), MSL),
- the results of laboratory tests and modelling which were carried out if necessary,
- a clear summary of the test findings,
- a summary of characteristic soil mechanical parameters of main soil types as well as the associated range of the parameters,
- a comprehensive description of the soil and
- a geotechnical site assessment.

## 4.2.2 Presentation of the results of field and laboratory tests

### 4.2.2.1 Field investigations

All surveys sites shall be illustrated in a site plan, and the findings shall be shown at the correct scale in accordance with DIN 4023 and the DIN EN ISO 22476 series of standards. These must result in an overall view of the various strata as well as discontinuities and local features in the soil which is necessary for design development. The site-based water depth and the associated reference system (e.g. chart datum (LAT), MSL) should be specified.

The measuring systems used for measuring exploration starting points shall be described and measurement uncertainties, tolerance and reference systems (e.g. chart datum (LAT), MSL) shall be stated (Note: the findings should be contrasted if several measuring systems are used). Also reference dimensions in relation to fixed points or reference lines shall be included as well as comparisons of target/actual co-ordinates.

The dates of the field investigations and any special observations made during drilling inspection shall be noted.

The methods used for drilling and sounding have to be explained in the geotechnical site survey reports submitted. If standardised methods have been used, reference to the standard is sufficient. In case of deviations from standard procedures reasons have to be provided, and the method used has to be described.

The geotechnical site survey reports shall include, as a matter of principle, the field reports of the borings carried out according to DIN EN ISO 14688-1, DIN EN ISO 14689-1, and DIN EN ISO 22475-1 and a report for measuring the exploration points in accordance with IHO (2008) for Order 1 surveys shall be included. If this is not possible in exceptional cases, a note shall be included stating that the reports can be inspected and where they can be inspected. The latter applies also to the soil samples taken.

If core samples have been taken, colour photos of the drilling cores shall be enclosed. Such colour photos do not replace an analysis and evaluation of the soil samples by an expert at the laboratory.

The data from penetration testing shall be documented taking into account DIN EN ISO 22476. As well as specifications for calculating, correlating and interpreting (classification) of sounding results, specifications regarding measurement accuracy or tolerance of the measuring procedures used as well as documenting protocol for calibration and quality control. It is recommended to plot the data from penetration testing against the drilling logs at the same location using a common reference system for height data (i.e. chart datum (LAT), MSL).

For construction measures in rock, discontinuities should be illustrated such that the relative frequency of individual directions of division surface is readily seen. Frequency, degree of separation, solidity and width of openings in the interstices should all be described.

All exploration sites with notes regarding gases and pollutants must be illustrated in a site plan. Concentrations should be drawn up in a table and in a drawing with temporal trends. All data that is important for assessing samples and for analysis shall be contained. The analysis procedures shall be named and reasons given if necessary.

#### **4.2.2.2 Laboratory tests**

The results of laboratory tests shall be fully documented and described for each typical soil property (e.g. grain size distribution curves, compression test results, shear test results), so that any interested reader will be able to interpret the results. The test set-up has to be described in each case. If standardised tests have been used, reference to the standard will be sufficient.

The results of compression tests shall be provided in the form of pressure settlement curves and time settlement curves, with indication of load stages and consolidation times. Documentation of the results shall also include data on equipment dimensions and the way of mounting the soil samples in the equipment. The results of soil strength tests shall be shown in conformity with applicable standards.

The results of the laboratory tests shall be provided in the form of tables, sorted by borings, sampling depths, and sample numbers.

#### **4.2.3 Summary of investigation results (ground description)**

The results of the field and laboratory tests shall be compiled in a geotechnical site description forming part of the geotechnical site survey reports.

Grain size distribution curves shall be combined to grain size bands of the main soil types where applicable. The ranges and mean characteristic values of the soil mechanical parameters of the main soil types shall be indicated for each exploration point. These data, if reasonable, should be compiled to establish typical foundation soil profiles for individual areas. If necessary, information should be provided regarding use of the characteristic soil mechanical parameters in the planned foundation design.

#### **4.2.4 General ground assessment**

The general ground assessment shall include an evaluation of the soil and subsoil properties at the project site with respect to its suitability for the construction of foundations for offshore structures, both with regard to load carrying properties and to the feasibility of different foundation concepts.

### **4.3 Soil and foundation expertise**

#### **4.3.1 Content of soil and foundation expertises**

The soil and foundation expertise must contain at least the following as an independent part of the geotechnical report according to DIN 4020 in the respective project phases:

- a general description of the site in geological and geotechnical terms,
- notes regarding the spatial orientation of discontinuities, provided they are relevant,
- the major construction data as foundation criteria,
- the geotechnical site assessment with reference to construction measures,
- a critical assessment of the findings regarding the findings listed in the geotechnical site survey report in coordination with the structural setup,
- specification of design profiles,
- determination of the soil characteristics and, if necessary, of the computation methods or computation model,
- if applicable, information about obstructions to driving and suitable methods for piling and mudmat installation,
- description of possible foundation designs including their geotechnical evaluation,

- the foundation proposal; it shall be shown in a suitable manner in the soil and foundation expertise (development phase) that the verification for structural safety and suitability for use of the foundation elements can be carried out as part of these foundation proposal. These illustrations are not necessary in the soil and foundation expertise in the construction phase as the verifications are included in the geotechnical design report in accordance with DIN EN 1997-1,
- notes for taking building ground behaviour under cyclical loads into account for further planning,
- if applicable, information about geological hazards (e.g. gas, earthquakes) and
- details concerning execution of construction.

#### 4.3.2 Information provided in the soil and foundation expertise

The results compiled in the geotechnical site survey report provide the basis for the soil and foundation expertise to be prepared by the geotechnical expert. Together, both reports form the geotechnical report in accordance with DIN 4020 in the respective project phase.

The soil and foundation expertise shall contain a synoptic description of the geological structure, the properties of on-site soil strata identified, and of the physical soil characteristics, and an evaluation of the ground under static/engineering aspects as well as civil engineering aspects. An indispensable part of the expertise is information about grain size distribution, the compactness of non-cohesive soils, condition of cohesive soils, the illustration of separation plans (Frequency, degree of separation, solidity and width of openings in the joints) and evaluation of the shear parameters and coefficients of stiffness in the geotechnical site survey report with regard to the requirements to be met. One or several calculation profiles must be drawn up for each structure, if required.

The soil and foundation expertise specifies the characteristic soil parameters that are relevant to the static analysis, at least the densities, stiffness moduli, and shear parameters as well as for static soil analyses in limit conditions of load-carrying properties and suitability for use and for limit values for foundation movement. Before establishing the characteristic rock parameters it must be decided whether a discontinuum (a solid model with trend surfaces) or a continuum (solid model with similar mechanical properties) is used for rocks that feature trend surfaces as a computation model. When establishing characteristic parameters anisotropy and inhomogeneities of the rock must be taken into consideration along with the expected direction of load. If required, the geotechnical expert may first discuss and agree these values with the developer, the design engineer, the responsible construction supervising authority or certification body in terms of the *Standard Design*, possibly also with the construction company taking into account tasks and requirements.

The soil and foundation expertise shall include a classification of soils by soil groups according to DIN 18196 and soil classes according to DIN 18300 and 18311.

The geotechnical expert shall prepare a recommendation for the foundation design. Also, an evaluation of soil properties with respect to piling and the installation of mudmats shall be part of the ground and foundation expertise. If the scope of investigations performed does not allow such an evaluation to be made, this should be pointed out in a note, and additional investigations should be proposed and performed at a later date.

Finally, the soil and foundation expertise shall also assess the risk of encountering obstructions to driving. In this context, not only the results of borings and penetration tests should be taken into account but particularly the results of the geological-geophysical study.

#### **4.4 Supplementary report on soil behaviour under cyclic loading**

##### **4.4.1 General**

With regard to the verification for foundation structures, the potential influence of cyclic loading on soil behaviour must be drawn up such as degradation, an accumulation of deformations and an accumulation of excess pore water pressure potentially as far as liquefaction (see also *Standard Design*).

##### **4.4.2 Supplementary report on soil behaviour under cyclic loading**

As part of the second release, the design engineer must describe the building ground behaviour under cyclical load whilst taking into consideration the design work from the geotechnical planner and plan a suitable study programme together with the geotechnical expert. Execution of the study programme is accompanied by the geotechnical expert and the results are assessed by him regarding the foundation system which has been selected. Close co-operation between the geotechnical planner and the geotechnical expert is required in this case. It is also possible that the planner's tasks are carried out by the geotechnical expert, who is then active on the design side.

The findings are then compiled in a *supplementary report regarding cyclical loads* which supplements the geotechnical design report with the parameters relevant to cyclical measurements.

### **5 Monitoring during construction (execution phase)**

Geotechnical elements within construction shall be monitored and inspected in accordance with typical rules, findings are documented and assessed in reports of findings by the geotechnical engineer.

### **6 Monitoring during operation**

If particular elements of the structural stability and serviceability verifications are not based on previously performed computations or testing of component parts or experience in general or in a particular case, proof of which can be provided, suitable monitoring instruments shall be provided and put into operation (observational method according to DIN EN 1997-1).

**Remarks:** The instrument monitoring concept in such cases is part of the structural stability documentation and constitutes a mandatory element of inspection during the operation phase. The type and scope of the investigations and length of the intervals as well as tolerances are determined by the geotechnical expert in co-ordination with the developer and the design engineer, taking into account the tasks to be performed and the requirements. Measurement results must be assessed on a periodic basis by the geotechnical planner to see if the facility behaves in accordance with the design. The geotechnical expert then adopts a position regarding the findings and assessments. The measurement results and their evaluation by the geotechnical expert have to be submitted periodically to the approval authority as agreed. Further issues are covered by *Standard Design*.

## **Part D: Minimum Requirements on site investigations for cable routes for the inter-array network and the power cables**

The objective of geophysical and geotechnical survey of cable route corridors is to gain sufficient information regarding the characteristics and the geology of the seabed such that cables can be installed in the proper manner. The findings of such investigations are used on the one hand to optimise a planned cable route corridor whilst taking unknown situations into account whilst also establishing a suitable installation method. The findings must therefore make it possible to determine the quality of the seabed regarding cable layering and to calculate the expected installation depth for the planned installation method (so-called “Burial Assessment”) within each part of the cable route corridor.

Measurement of the cable route corridor must cover the entire cable corridor. This applies to both the horizontal coverage as well as the measurement of vertical sections. It is usually expedient to separate the measurement into two independent exploration phases which are organised into one measurement cruise.

The first phase contains the geophysical measurements so that a linear insight and overview of the measured area is gained. During this first measurement cycle, bathymetric measurements shall be carried out with a multi-beam echosounder (MBES), recording of the surface of the sea bed shall be carried out with SSS as well as subbottom profiling (e. g. boomers, chirp sonar pinger, parametric echosounder) for determining geological units within the profile. It is strongly recommended to combine the SSS measurement with metal detection measurements. Detailed requirements of the respective measuring principle can be seen in Table 10.

The scope of sediment sampling or geotechnical investigations is established on the basis of the assessed and interpreted geophysical measurement data. In case of cable route corridor measurements previously carried out in the EEZ within the North Sea, the median sampling or probing intervals were typically up to 4 km in geologically homogeneous cable corridor sections, but in more geologically complex cable corridor sections it was typically 0.5 km. It may be necessary to go under this interval to clarify complicated geological conditions.

After assessing and interpreting the geophysical test results, locations are selected for the geotechnical and geological sampling based on the knowledge gained, and such locations should enable a comprehensive knowledge of the geological conditions to be gained along the cable route corridor with regard to the installation of cables. This covers the sampling of all geophysical units which are identified and mapped on the basis of the investigation findings with SSS or subbottom profiling measurements. Locations which appear to make geological interpretations from geophysical measurements more complicated should also be sampled. If the geophysical test results show conspicuous and/or unusual seismic reflectors then it is strongly recommended that these are investigated with geotechnical methods. This is particularly so when e. g. peat, clay lenses, till etc. are expected. For sampling or geotechnical examination of the sediments, vibrocoring equipment, piston and gravity corers, grippers as well as cone penetration testing (CPT) can be used. Further details regarding minimum requirements can be found in Table 10.

The results of cable corridor measurements are illustrated in an independent, comprehensive report. Alongside a short project description it is important to name the persons involved in the project, describe the systems used for gathering data as well as illustrate the measuring procedures. Data processing as well as subsequent assessment and interpretation must also be explained. Geophysical and geotechnical findings shall be presented separately before a

summarising geological assessment is added. In addition, for classification in accordance with DIN 18311, characteristics of undrained shear strength (for cohesive soils) and the density (non-cohesive soils) should also be stated. Further details regarding reporting and cartographic representations can be seen in Table 10.

**Table 10:** Requirements of the geological-geotechnical survey and investigation for cable route corridors.

	<b>Corridor investigation</b>	<b>Monitoring</b>
<b>Objectives</b>	<ul style="list-style-type: none"> <li>Establishing the actual installation route and the cable length</li> <li>Creating the planned cable route corridor with regard to bathymetry and morphology incl. all aspects relevant to cable installation</li> <li>Investigating the composition of sediment, the geological bedding conditions and the geotechnical properties of the upper levels of the seabed incl. all relevant aspects for cable installation.</li> <li>Mapping wrecks, other obstacles and also munition if there is evidence that such has been deposited</li> <li>Exact positions of existing cables and pipelines</li> </ul>	<ul style="list-style-type: none"> <li>Detecting potential hazards to the cable</li> <li>Monitoring riprap or similar measures to protect the cable</li> <li>Detecting the mandatory minimum level of cover with sediment to ensure that the cable is protected from hazards</li> </ul>
<b>Scope</b>	<ul style="list-style-type: none"> <li>Investigating the planned cable route corridor using geological, geophysical and geotechnical methods</li> <li>Area-covering survey of a corridor, the width of which corresponds to the width of the planned cable route corridor plus a clearance of at least 50m on both sides of the corridor, with side scan sonar and multi-beam echosounder (MBES).</li> <li>Linear measurement of the planned cable route corridor with high-resolution subbottom profiling methods</li> </ul>	<ul style="list-style-type: none"> <li>Monitoring of the entire cable route corridor in the first few years</li> <li>After a suitable database has been submitted, modified monitoring intervals can be requested for periodic investigations</li> </ul>
<b>Timing</b>	<ul style="list-style-type: none"> <li>As a one-off for planning installation, a repeat measure is required close to the installation date in morphologically changeable areas</li> </ul>	<ul style="list-style-type: none"> <li>In the initial years after installation check once per year, early on in the year</li> </ul>

<b>Methods</b>	<ul style="list-style-type: none"> <li>• Multi-Beam Echosounder, MBES; data density sufficient to generate a digital terrain model with a resolution of at least 1 m</li> <li>• Positioning of the ship and the firmly installed sensors as well as the accuracy for reduced depths modelled on IHO (2008) for Special Order Surveys</li> <li>• Side scan sonar with a frequency of 100 kHz or higher, measuring area max. 2 x 100 m, recognition of objects &gt; 0.5 m grid spacing; digital recording, cruising speed chosen such that the area is fully covered; positioning of the device is better than 10 &lt;m</li> <li>• Subbottom profiler, chirp sonar or alternative systems with comparable or better performance; vertical resolution of at least 0.5 m</li> <li>• Vibrocorer or cone penetration testing up until the planned installation depth of the cable, intervals are established on the basis of geophysical findings</li> <li>• Magnetometer or an active metal detection system</li> <li>• Thermal conductivity measurements in the cable route corridor area, within which cable operations are affected to low thermal conductivity of the seabed.</li> </ul>	<ul style="list-style-type: none"> <li>• Multi-Beam Echosounder, MBES; data density sufficient to generate a digital terrain model with a resolution of at least 1 m</li> <li>• Positioning of the ship and the fixedly installed sensors as well as the accuracy for reduced depths modelled on IHO (2008) for Special Order Surveys</li> <li>• Side scan sonar with a frequency of 100 kHz or higher, measuring area max. 2 x 100 m, recognition of objects &gt; 0.5 grid spacing; digital recording, cruising speed chosen such that the area is fully covered; positioning of the device is better than 10 m</li> </ul>
<b>Presentation of results</b>	<ul style="list-style-type: none"> <li>• Cartographical illustration of all findings of measurements in an integrated format in alignment charts (horizontal scale 1 : 5000, vertical scale 1 : 100 or 1 : 150)</li> <li>• The presentation of all measuring results in a report in an integrated format; maps and reports should usefully supplement each other and make reference to each other where necessary; documentation of equipment used, time and course of measuring, measuring conditions, problems etc. shall all be recorded in the report</li> <li>• Special maps for landings and cable and pipeline intersections</li> <li>• Maps must also be in GIS or CAD format</li> </ul>	<ul style="list-style-type: none"> <li>• Cartographical illustration of all findings of measurements in an integrated format in alignment charts (horizontal scale 1 : 5000, vertical scale 1 : 100 or 1 : 150)</li> <li>• Illustration of all measurement results in a report in integrated format. Maps and reports should usefully supplement each other and make reference to each other. Documentation of equipment used, time and course of measuring, measuring conditions, problems etc. shall all be recorded in the report</li> <li>• Maps must also be in GIS or CAD format</li> </ul>

## Annex 1: References

- Balthes, R., Thiele, R. und G. v. d. Zwaag, 2005: Geotechnische Erkundungen im nearshore- und offshore-Bereich zur Ermittlung von Bodenkennwerten für die Bemessung von Pfahlgründungen (Geotechnical exploration in nearshore and offshore areas for determining sediment characteristics for measuring pile foundations). Pfahl-Symposium 2005, 24.-25.02.2005, TU Braunschweig.
- Fugro-McClelland Ltd., 1993: UK Offshore Site Investigation and Foundation Practices, FML Report No. 92/2549-1(03). In: Health and Safety Executive, Offshore Technology Report – OTO 93024, Sheffield.
- Lunne, T, Robertson, P.K. and Powell, J.J.M., 1997: Cone Penetration Testing in Geotechnical Practice, Blackie Academic & Professional, London.
- McClelland, B. und M. D. Reifel, 1986: Planning and Design of Fixed Offshore Platforms. Van Nostrand Reinhold Company Inc., New York.

## Annex 2: Standards, guidelines and codes of practice

- API RP 2A-WSD. Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms – Working Stress Design. 21<sup>st</sup> Edition, American Petroleum Institute, 2000.
- Classification Notes No. 30.4. Foundations. Det Norske Veritas.
- DIN 1054. Soil – verification of safety in earthwork and foundation work – supplementary guidelines to DIN EN 1997-1.
- DIN 4020 Geotechnical investigations for civil engineering purposes – supplementary guidelines to DIN EN 1997-2
- DIN 4023. Geotechnical exploration and investigations – Illustration of results of borings and other direct investigations.
- DIN 4094-2. Soil – Field investigations, part 2: Borehole Dynamic Probing.
- DIN 18121-1. Investigations into sediment samples – Water content – Part 1: Using kiln drying to determine results.
- DIN 18121-2. Soil – Investigations into sediment samples – Water content – Part 2: Using a summary process to determine results.
- DIN 18122-1. Soil, Investigations into sediment samples – State boundaries (Consistency limits) – Part 1: Determining the liquid limit and the plastic limit.
- DIN 18122-2. Soil – Investigations into sediment samples – State boundaries (Consistency limits) – Part 2: Determination of the shrinkage limit.
- DIN 18123. Soil, Investigations into sediment samples – Determining particle size distribution.
- DIN 18125-1. Soil, Investigations into sediment samples – Determining soil density – Part 1: Laboratory tests.
- DIN 18126. Soil, investigation and testing – Determination of density of non-cohesive soils for maximum and minimum compactness
- DIN 18129. Soil, Investigations into sediment samples – Determining lime content.
- DIN 18130-1. Soil – Investigations into sediment samples – Determining the coefficient of permeability of soil – Part 1: Laboratory tests.
- DIN 18135. Soil – Investigations into sediment samples – Oedometer consolidation test. Soil, investigation and testing – Determination of shear strength – Part 2: Triaxial test.
- DIN 18137-3. Soil, Investigations into sediment samples – Determination of shear strength – Part 3: Direct shear test.
- DIN 18196. Earthworks and foundations – Soil classification for civil engineering purposes.
- DIN 18300. German construction contract procedures (VOB) – Part C: General technical specifications in construction contracts (ATV) – Earthworks.
- DIN 18311. German construction contract procedures (VOB) – Part C: General technical specifications in construction contracts (ATV) – Dredging work.
- DIN EN 1997-1. Eurocode 7: Geotechnical design – Part 1: General rules.
- DIN EN 1997-1/NA. National Annex – Nationally determined parameters. Eurocode 7: Geotechnical design – Part 1: General rules.
- DIN EN 1997-2. Eurocode 7: Geotechnical design – Part 2: Ground investigation and testing.
- DIN EN 1997-2/NA. National Annex – Nationally determined parameters. Eurocode 7: Geotechnical design – Part 2: Ground investigation and testing.
- DIN EN ISO 10012: Standard on Measurement Management Systems – Requirements for Measurement Processes and Measuring Equipment.
- DIN EN ISO 14688-1. Geotechnical Investigation and testing – Identification and classification of soil – Part 1: Identification and description (ISO 14688-1); German version EN ISO 14688-1.
- DIN EN ISO 14689-1. Geotechnical Investigation and testing – Identification and classification of rock – Part 1: Identification and description (ISO 14689-1); German version EN ISO 4689-1.

- DIN EN ISO 19901-8. Petroleum and natural gas industries – Specific requirements for offshore structures – Part 8: Marine soil Investigations (ISO/DIS 19901-8:2013); English version prEN ISO 19901-8.
- DIN EN ISO 22475-1. Geotechnical Investigation and testing – Sampling methods and groundwater measurements – Part 1: Technical principles for execution (ISO 22475-1); German version EN ISO 22475-1.
- DIN EN ISO 22476-1. Geotechnical Investigation and testing – Field investigations – Part 2: Electrical cone and piezocone penetration test (ISO 22476-1); German version EN ISO 22476-1.
- DNV-OS-J101. Design of Offshore Wind Turbine Structures. Det Norske Veritas.
- Empfehlungen des Arbeitskreises „Pfähle“. EA-Pfähle recommendations by the Piling working group of the German Society for Geotechnics (DGGT) Recommendations of the Piling working group, publisher. Deutsche Gesellschaft für Geotechnik e.V., 2<sup>nd</sup> edition, 2012, Ernst & Sohn, Berlin.
- Recommendations of the Soil Dynamics working group of the Deutsche Gesellschaft für Geotechnik, 1<sup>st</sup> edition, 2002, in-house publication from the Geotechnical Institute of the Technische Universität Berlin
- Guideline for the Certification of Offshore Wind Turbines. GL Renewables Certification, Hamburg.
- IHO (2008): Standards for Hydrographic Surveys, Special Publication No. 44, 5<sup>th</sup> Edition, International Hydrographic Bureau, Monaco.
- Construction standards – Minimum requirements regarding the construction of offshore structures in the Exclusive Economic Zone (EEZ), Federal Maritime and Hydrographic Agency, Hamburg and Rostock, BSH no. 7005.

**Annex 3: List of abbreviations**

API	American Petroleum Institute
EEZ	exclusive economic zone
BDP	Borehole Dynamic Probing
BSH	German Federal Maritime and Hydrographic Agency
CAD	Computer Aided Design
CD	Chart Datum
CU	Consolidated undrained shear test
CCV	Consolidated constant volume test
CPT	Cone Penetration Test(s)
CPTu	Piezocone Penetrometer Test(s)
D	Diameter
DGGT	Deutsche Gesellschaft für Geotechnik e.V.
DIN	Deutsche Industrienorm
DNV	Det Norske Veritas
EA	Recommendations of the Working Group
EC	Eurocode
EN	European Norm
ETRS 89	European Terrestrial Reference System 1989
EV	Design engineer
FPGt	Geotechnical planner
GIS	Geographic Information System
GK	Geotechnical category
IHO	International Hydrographic Organisation
ISO	International Standardisation Organisation
LAT	Lowest Astronomical Tide
MBES	Multibeam Echosounder
MSL	Mean Sea Level
NA	National Application Document
OS	Offshore Standard
SeeAnIV	German Marine Facilities Ordinance
SSS	Side Scan Sonar
SVGt	Geotechnical engineer
UTM	Universal Transversal Mercator Grid System
UU	Unconsolidated undrained shear test
UW	Transformer station
WEA	Wind energy structure(s)
WGS 84	World Geodetic System 1984
WSD	Working Stress Design